The OPERA Neutrino Oscillation Experiment
First results of the first year data taking

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on behalf of the OPERA collaboration
OPERA is an international collaboration made of ~200 physicists from 36 institutions and 13 countries.
1998 Atmospheric neutrino anomaly: deficit of $\nu_\mu$ with zenith angle and energy dependence. $\rightarrow$ OSCILLATION

CHOOZ: final flavour not $\nu_e$ ...

$\text{Best fit: } \Delta m^2 = 2.5 \times 10^{-3} \text{eV}^2; \sin^2 2\theta = 1$

1998 CNGS beam design

2000 direct observation of $\nu_\tau$ in nuclear emulsions (DONUT)

2000 OPERA proposal
The OPERA experiment

- OPERA (Oscillation Project with Emulsion tRacking Apparatus) is a long baseline neutrino oscillation experiment

- The goal of the experiment is to directly measure for the first time neutrino oscillation in an appearance mode

- Using an almost pure $\nu_\mu$ beam, the $\nu_\mu \rightarrow \nu_\tau$ transition is detected by observing the $\tau$ lepton decay, induced after a neutrino-lead CC interaction

- $\tau$ lepton decay is observed by means of Emulsion Cloud Chambers

- The detector is located on the CNGS (CERN to Gran Sasso) beam line at a distance from the neutrino source of 730 km

**OPERA**

provide an unambiguous evidence for

$\nu_\mu \rightarrow \nu_\tau$ oscillation in the region of atmospheric neutrinos

by looking for

$\nu_\tau$ appearance

in a pure $\nu_\mu$ beam
The CNGS beam

- The CNGS is a conventional neutrino beam: 400 GeV/c (protons) CERN SPS hit a graphite target producing pions and kaons which decay in flight and produce neutrinos.

- The beam is optimized for $\nu_\tau$ appearance in the atmospheric oscillation region. The present best fit is now:

$$\Delta m_{23}^2 = (2.43 \pm 0.13) \times 10^{-3} \text{ eV}^2$$

$$\sin^2 2\theta_{23} = 1.0$$

- Although the maximum of oscillation probability at 730 km is at about 1.5 GeV, we need to take into account the $\nu_\tau$ CC cross section and the production threshold of 3.5 GeV.
Detection principle

- The detection of the $\tau$ lepton requires an identification of a “kink” or “trident” topology.
- The detector must fulfil the following requests:
  1. Large mass due to small CC cross section (lead target)
  2. Micrometric and milliradian resolution to observe the kink (photographic emulsions)
  3. Select neutrino interactions (electronic detectors)
  4. Identify muons and their charge to reduce charm background (electronic detectors)

An hybrid detector (emulsions + electronic detectors) like OPERA fulfils all these requirements.

$\nu_\tau \rightarrow e^- (17.8\%)$
$\tau \rightarrow \mu^- (17.4\%)$
$\tau \rightarrow h^- (49.5\%)$
$\tau \rightarrow 3h^- (15.2\%)$
**τ identification**

- The target is divided in about 152000 ECC's (Emulsion Cloud Chamber), so called “bricks”. Each brick weights 8.3 kg.

- One brick is made by a sandwich of:
  1. 56 (1mm) Pb sheets
  2. 57 (300μm) FUJI emulsion film
  3. 2 (300μm) changeable sheets
Expected signal and background

**Full mixing after 5 years run at 4.5x10^{19} pot / year**

Efficiency before $\tau$ identification: $\varepsilon_{\text{trigger}} \times \varepsilon_{\text{brick}} \times \varepsilon_{\text{geom}} \times \varepsilon_{\text{vertex location}}$

99% x 80% x 94% x 90%

Signal is proportional to $(\Delta m^2)^2$

<table>
<thead>
<tr>
<th>$\tau$ decay channels</th>
<th>$\varepsilon$(%)</th>
<th>BR(%)</th>
<th>$\Delta m^2$</th>
<th>$\Delta m^2$</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau \rightarrow \mu$</td>
<td>17.5</td>
<td>17.7</td>
<td>2.9</td>
<td>4.2</td>
<td>0.17</td>
</tr>
<tr>
<td>$\tau \rightarrow e$</td>
<td>20.8</td>
<td>17.8</td>
<td>3.5</td>
<td>5.0</td>
<td>0.17</td>
</tr>
<tr>
<td>$\tau \rightarrow h$</td>
<td>5.8</td>
<td>49.5</td>
<td>3.1</td>
<td>4.4</td>
<td>0.24</td>
</tr>
<tr>
<td>$\tau \rightarrow 3h$</td>
<td>6.3</td>
<td>15</td>
<td>0.9</td>
<td>1.3</td>
<td>0.17</td>
</tr>
<tr>
<td>ALL</td>
<td>$\varepsilon \times \text{BR}=10.6%$</td>
<td></td>
<td>10.4</td>
<td>14.9</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Background sources:
- Charm production and decays
- Hadron re-interactions in lead
- Large-angle muon scattering in lead

Occur if primary muon is not detected and possible wrong charge measurement of secondary muon. **Muon ID is a crucial issue for the experiment!**
The OPERA detector design

- The detector is located in the hall C at LNGS (Laboratori Nazionali Gran Sasso)
- The total target mass is 1.35 kton
- Each spectrometer consists of 22 RPC planes in magnetic field (1.5 T) and 6 Drift Tubes planes, to identify muons and measure charge and momentum
- Each target consists of 27 lead-emulsion brick walls alternated to scintillator strips planes to select the brick containing the neutrino interaction.
The OPERA detector today

- Electronic fully instrumented and tested since 2007
Target tracker and Spectrometer

- The main goals of the target tracker are the trigger on the neutrino events and the identification of the brick to be extracted and then analysed.
- It is made of plastic scintillator strips, each with a wavelength shifting fibre.
- The fibres are connected in groups of 64 to multi-anode Hamamatsu PMTs at both ends.

<table>
<thead>
<tr>
<th># p.e. per mip (2.15 MeV)</th>
<th>&gt; 5</th>
</tr>
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<tbody>
<tr>
<td>Detection efficiency</td>
<td>99%</td>
</tr>
<tr>
<td>Brick finding efficiency</td>
<td>80%</td>
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</tbody>
</table>

- The goal of the spectrometer is the momentum measurement and charge discrimination.
- In particular it is used to measure and identify muons, in order to reduce charm background.
- It is made by inner tracker (RPC planes) and precision tracker (Drift Tubes) in a 1.5 T magnetic field.
Brick target

- 146621 bricks of nuclear emulsions

- 5000 bricks more will be added at the end of 2008 once additional lead will be delivered
The automated microscopes

**OFF-LINE DATA TAKING**

~30 bricks will be daily extracted from the target and analyzed by using high-speed automated systems. Scanning labs are ready with ~40 microscopes available, shared in Japan and Europe.

**European scanning system**
- 90%–95% track finding efficiency (slope < 0.5 mrad)
- Customized commercial optics and mechanics
- Software coded algorithms
- Asynchronous DAQ software

**S-UTS (Japan)**
- High speed CCD camera (3 kHz)
- Piezo-controlled objective lens
- Hard-coded algorithms
Event finding

Detector scale (10 m)

Brick scale (10 cm)

Vertex scale (5 mm)
CNGS intensity

Fri 20/6
3 cycles

Wed 18/6 17:00
Start of commissioning at low intensity

Extraction 1

Extraction 2

Beam loss, vacuum accident 27/6-2/7

10/7 21:00
Earth fault on the PS magnet
PS magnet repair
no beam until Fri 18/7 23:08

18KV cable accident 25/7

Long MD stop + MTE kicker problem
7/7 6:00 – 10/7 12:00

PS septum + Long MD
8-14/8

Horn filters

3/11 8:00

Horn filters

PS vacuum

2.0E13 pot

2.0E13 pot
CNGS integrated intensity

Beam loss, vacuum accident 27/6-2/7

Wed 18/6 17:00
Start of commissioning at low intensity

1.782E19 pot

Unix Time

Horns filters 19-20/10
18KV cable accident 25/7
6-8/10 MD

10/7-18/7 Earth fault on the PS magnet

CNGS quadrupole 14-17/9

Horn + PS vacuum Week 1/9

PS septum + Long MD 8-14/8

Long MD stop + MTE kicker problem
17/7 6:00 + 10/7 12:00

3/11 5:00
1.782E19 pot

3/11 8:00
2008 Run

- Started since June 18th, end on November 3rd

- Beam performance for the 2008 run:

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>60% (expected 80%)</th>
</tr>
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<tbody>
<tr>
<td>Intensity (p.o.t. / extraction)</td>
<td>2x10^{13}</td>
</tr>
<tr>
<td>Integrated p.o.t.</td>
<td>1.782x10^{19}pot (80% of the expectations)</td>
</tr>
</tbody>
</table>

- Detected interactions:

<table>
<thead>
<tr>
<th>Recorded on time event</th>
<th>10100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candidate Interaction (In the target)</td>
<td>1700</td>
</tr>
</tbody>
</table>

\[ \leq 1 \tau \text{ event considering efficiency} \]
Vertex location breakdown by using a sub-sample of the measured events

Vertex location efficiency (3-11-2008):

**Charged-current:**
- Pessimistic case = 86%
- Optimistic case = 96%

In the proposal we quoted 93%

**Neutral-current:**
- Pessimistic case = 74%
- Optimistic case = 89%

In the proposal we quoted 81%
Topological and kinematical analysis of first charm event

The main background source is the hadron reinteraction

The probability that a hadron reinteraction has a $P_T$ larger than 600 MeV is $4 \times 10^{-4}$
Topological analysis of the second charm event

From a topological point of view the main sources of background are:

- Kaon decay: probability $10^{-4}$
- Hadron reinteraction: probability $1 \times 10^{-5}$

Further reduction from kinematical analysis (in progress).

A first result is shown here below:

Only 4-5 plates available for momentum measurement. Brick to brick is in progress.
Conclusions

- The OPERA detector and its infrastructure successfully operated during 2008 CNGS Run
- Emulsion scanning laboratories completely operational
- Partial recovery of the beam after a rather problematic start: $1.782 \times 10^{19}$ instead of $2.2 \times 10^{19}$ p.o.t.
- About 1700 events in the bricks: $\leq 1 \tau$ but extremely valuable sample to fine tune OPERA analysis and to estimate efficiencies and background
- 2009 CNGS run aim is to at least double the integrated intensity and collect the first $\tau$ candidate(s)